Real-time beamforming synthetic aperture radar

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ABSTRACT

This paper discusses the concept and design of a real-time Digital Beamforming Synthetic Aperture Radar (DBSAR) for airborne applications which can achieve fine spatial resolutions and wide swaths. The development of the DBSAR enhances important scientific measurements in Earth science, and serves as a prove-of-concept for planetary exploration missions. A unique aspect of DBSAR is that it achieves fine resolutions over large swaths by synthesizing multiple cross-track beams simultaneously using digital beamforming techniques. Each beam is processed using SAR algorithms to obtain the fine ground resolution without compromising fine range and azimuth resolutions. The processor uses an FPGA-based architecture to implement digital in-phase and quadrature (I/Q) demodulation, beamforming, and range and azimuth compression. The DBSAR concept will be implemented using the airborne L-Band Imaging Scatterometer (LIS) on board the NASA P3 aircraft. The system will achieve ground resolutions of less than 30 m and swaths of 10 km from an altitude of 8 km.

Keywords: SAR, beamforming, radar, earth science, planetary exploration.

1. INTRODUCTION

The DBSAR concept combines digital beamforming and onboard processing to achieve fine resolutions over large swaths, in real-time. The technology development benefits many earth science applications that require fine resolution measurements and large coverage such as measurements of surface water, polar ice sheet velocity, snow thickness, surface deformation, land cover usage, and vegetation biomass. This technology will also benefit planetary exploration missions is search of water and resources, like the upcoming Robotic Lunar Exploration Program (RLEP) and Mars Scout missions.

The synthetic aperture radar (SAR) is an instrument that can provide fine resolutions by synthesizing large apertures in the along track dimensions [1]. However, SAR systems are inherently narrow swath because of imposed ambiguity limitations. A ScanSAR system can provide wider swaths by steering the antenna beam in order to cover more than one swath [2]. However, their increased coverage results in a degraded image resolution because of the scanning constraints imposed on the swath and azimuth resolution [3]. ScanSAR systems that provide continuous coverage can also generate large data volumes that exceed the capacity of onboard data recorders.

DBSAR employs a phased array radar, and a FPGA-based real-time processor to implement digital beamforming and SAR processing. The system can generate high resolution images over multiple antenna beams without compromising range and azimuth resolutions. Furthermore, each beam can be synthesized with different beam widths and side lobe levels so as to maintain constant swath widths and minimize side lobe contamination.

DBSAR will be tested on board of the NASA P3 aircraft based at the Wallops Flight Facility (WFF). The flight tests are scheduled in the fall 2006 when DBSAR will gather and generate real-time high resolution images over wide areas of the eastern shore of the United States.

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2. THE DBSAR CONCEPT

The DBSAR high resolution imager capability leverages two ongoing efforts at the NASA Goddard Space Flight Center (GSFC). The first is the development of the L-Band Imaging Scatterometer [3], a phased array radar recently designed and built at GSFC for the development and testing of new radar techniques. The second is the design of a multi-channel, reconfigurable data acquisition and real time processor system that will be used to implement the Digital Beamforming Synthetic Aperture Radar (DBSAR) processor.

DBSAR will operate in stripmap mode while flown on board of the NASA P3 aircraft as depicted in figure 1. The nominal flight altitude planned for the proof-of-concept is 8 km. As the aircraft flies at a speed of 100 m/s, on a leveled trajectory above the surface, the radar transmits wide beam pulses at a rate of 200 pulses per second. The wide beam is achieved by energizing a small section of the antenna array on transmission. As the pulses illuminate the entire field of view, radar signals are backscattered towards the antenna from a wide swath area. On return, the signals are received through the full antenna array, and then filtered, amplified, and down-converted to an intermediate frequency (IF) centered at 20 MHz. At this stage, the IF signals are routed to the digital receiver where analog-to-digital conversion takes place.

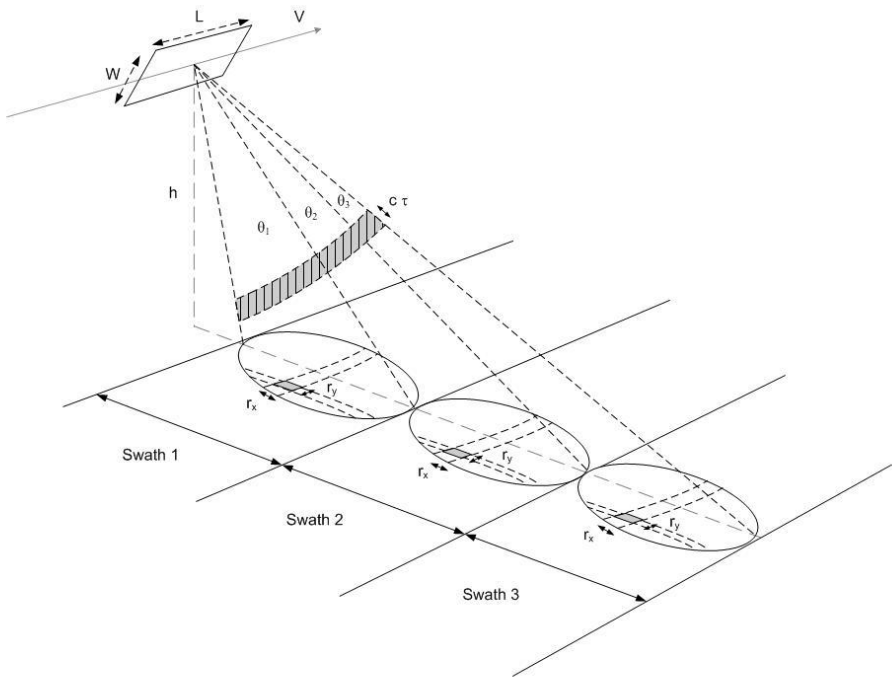

Figure 1 DBSAR provides beamforming, fine resolutions, and large swaths.

5. SUMMARY

DBSAR is a technology development aimed at demonstrating a new processing capability which enables beam synthesis, fine resolutions, and large swaths. DBSAR implements digital beamforming and SAR processing to obtain fine resolutions over large swaths, without degradations in range and azimuth resolutions. The DBSAR technology will benefit a number of Earth science and planetary exploration applications that require real-time processing, fine resolution, and large coverage.

The DBSAR concept employs the NASA L-band imaging scatterometer (LIS) and a real-time reconfigurable processor. The phased array architecture in LIS permits the generation of wide antenna beams on transmission pulses which illuminate large swaths. On receive, the real time processor synthesizes multiple narrow beams, and performs range and azimuth compression. The DBSAR data system is a reconfigurable real-time processor whose core consists of three Altera Stratix II FPGAs. The processor architecture is capable of high computational power at very high speeds.

DBSAR will explore additional capabilities, such as ScanSAR and unfocused SAR. The processor will also be reconfigured with other non SAR algorithms in support of other research areas at GSFC. DBSAR will begin flight testes on board of the NASA P3 aircraft in the fall 2006.